A ROBUST BIDIRECTIONAL LOW-VELOCITY PROBE FOR FLAME AND FIRE APPLICATION

by
B.J. McCaffrey
Center for Fire Research
Program for Physics and Dynamics
National Bureau of Standards
Washington, DC
and
G. Heskestad
Factory Mutual Research Corporation
Norwood, Massachusetts

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BRIEF COMMUNICATIONS

A Robust Bidirectional Low-Velocity Probe for Flame and Fire Application

B. J. McCAFFREY
National Bureau of Standards
and
G. HESKESTAD
Factory Mutual Research Corporation

Various new techniques have recently been developed that are capable of measuring the low velocity of buoyancy-driven flows associated with small to medium size fires. Ion deflection and fluidic devices, the laser Doppler anemometer and instruments utilizing auto-correlation techniques, are all commercially available and are excellent "bench top" research tools. They may, however, prove to be too delicate or require too careful alignment/calibration as well as elaborate electronic equipment for signal processing to be practical for the rigor and hostility of real fire environments. Additionally, the hot wire anemometer, very sensitive at low flows, is extremely fragile in a smoky atmosphere and inherently responds to temperature fluctuations more easily than velocity fluctuations despite temperature compensation.

Recently a new flow measuring device with the capability of bidirectional operation and angular insensitivity to about $\pm 50°$ has been described [1]. The new device possesses two features ideally suited for application in fire research, in addition to being as rugged as a stainless steel pitot-static tube: angular insensitivity, which allows a more accurate assessment of velocity where flow angles are difficult to predict; and secondly, owing to its symmetric nature, the probe responds to flow in either direction. This bidirectional property allows the probes to be located without prior knowledge of flow direction. Similarly, the probes will respond correctly when the flow at a point reverses its direction, for example when the exit neutral plane is lowered as a room fills during the buildup of a fire or when transient recirculation is occurring (see for example [3]). Furthermore the probe's larger size inlet circumvents problems associated with water droplet and debris formation present in small diameter pitot-static tubes.

The probe (Fig. 1) consists of a short piece of stainless steel tubing ($L/D = 2$) with a diaphragm in the center and two taps drilled close to, and on either side of the diaphragm. The tube axis is aligned with the flow, the upstream tap sensing the stagnation pressure, the downstream tap sensing a pressure slightly less than static. The small tubes used to carry the pressure signals also serve as mounting support for the probe. In constructing probes of differing diameter only the L/D scaling was preserved in the present investigation. The diameter and spacing of the support tubes as well as the wall thickness of the cylindrical probe body and diaphragm were all similar. For the probes used, varying in diameter from $D = 12.7$ to 25.4 mm, the resulting departures from geometric similarity were not considered significant enough to influence the probe calibration. Four different diameter probes were used in the present evaluation. Figure 2 shows the response of the probes in the low flow viscous regime. The output of the probe is given in terms of the square root of the ratio of the indicated pressure head to the velocity head plotted against Reynolds number, the asymptotic value (large Re) being about 1.08 versus 1.0 for a pitot-static tube.

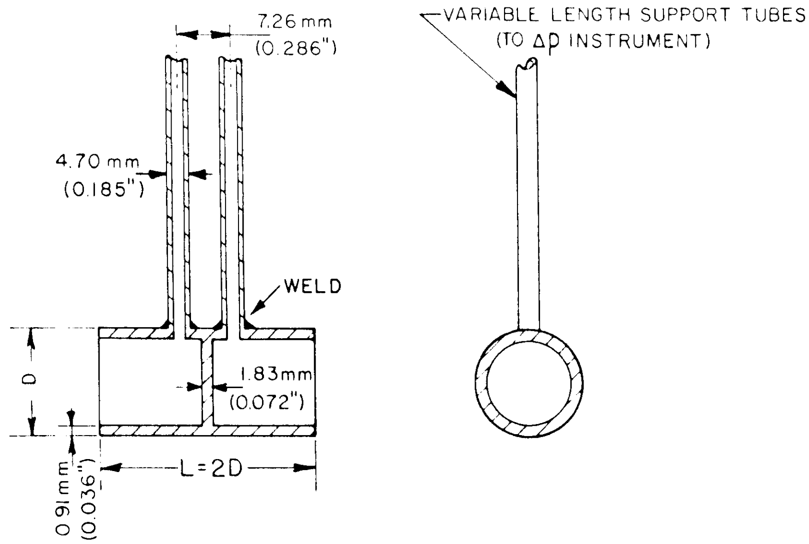

Fig. 1. Bidirectional probe.

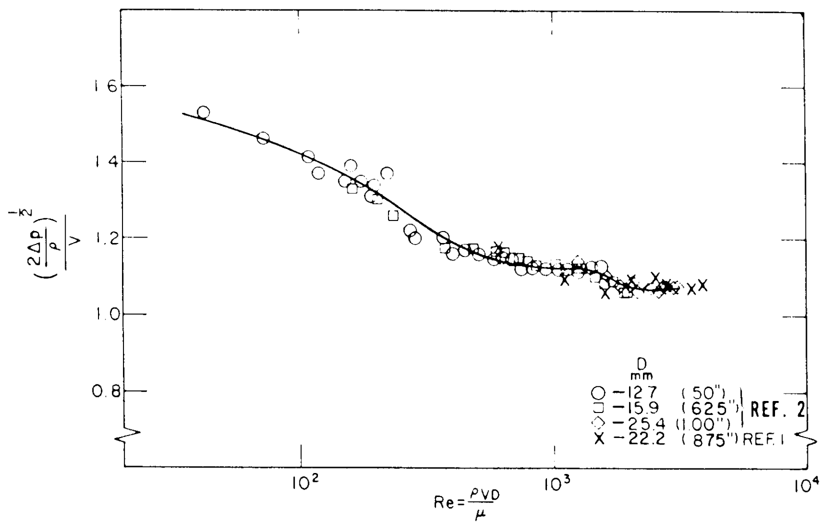

Fig. 2. Probe response versus Reynolds number.

The pressure differences were measured with a sensitive electronic manometer; the uniform low velocity flows were provided in two independent facilities described in [1] and [2]. Basically a hot wire anemometer and pitot-static tube, where appropriate, were used to determine the stream velocity. For data reduction via computer the polynomial curve fit obtained for the points shown in Fig. 2 is:

$$\frac{(2\Delta p/\rho)^{1/2}}{V} = 1.533 - 1.366 \times 10^{-3}\ \mathrm{Re} + 1.688 \times 10^{-6}\ \mathrm{Re}^2 - 9.706 \times 10^{-10}\ \mathrm{Re}^3 + 2.555 \times 10^{-13}\ \mathrm{Re}^4 - 2.484 \times 10^{-17}\ \mathrm{Re}^5$$

This representation is valid for $40 < \mathrm{Re} < 3800$ accurate to about 5%.

Insensitivity to inclination angle is demonstra-

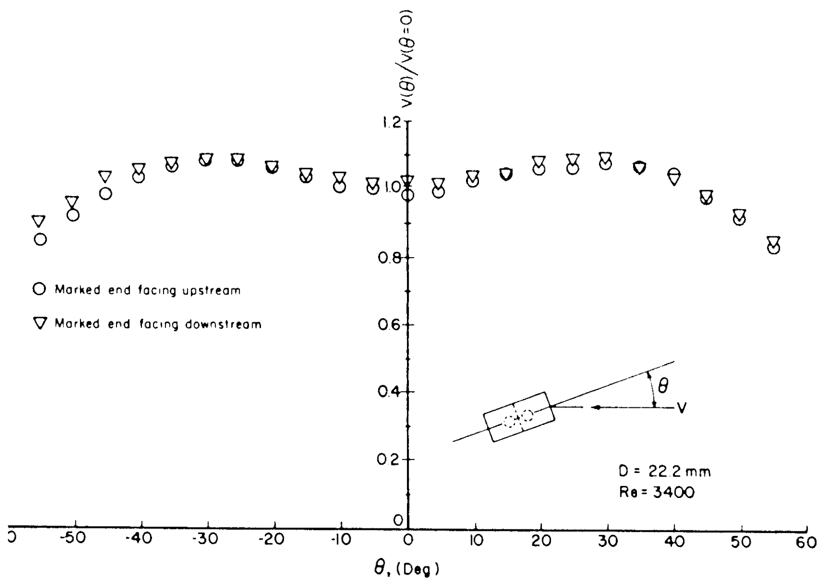

Fig. 3. Angular sensitivity of prototype in plane normal to axes of support tubes.

$\times 10^{-0} Re^3$

$\times 10^{-17} Re^5$

$e < 3800$

demonstra-

ted in the plot of Fig. 3. The probe will measure the resultant mean velocity within ± 10 percent provided the approach-flow direction is known to be within approximately 50 degrees of the probe axis at either end of the probe.

The practical advantages of angular insensitivity and the bidirectional capability far outweight any disadvantage associated with calibration due to the low Reynolds number nonlinear effect. For example, .025 m (1 in.) probes would not be unreasonable in the doorway of a full size room. Using a uniform calibration constant of 1.08 would result in a maximum error of about 7% down to velocities of .304 m/sec (1 ft/sec, Re = 520). For lower velocities or more accuracy the calibration of Fig. 2 can be used. However it should be kept in mind that, owing to the quadratic proportionality between pressure and velocity, for velocities very much lower than .304 m/sec the difficulties will probably be in the resolution of the transducer and not with the calibration constant. Also buoyancy effects in the lead tubes can be encountered; it is recommended that the probes be installed horizontally with sufficient leads so that the transducers can be located outside the burning room or other facility at the same height as the probe. Extensive examples of the bidirectional capability of the probe are contained in [2] and [4].

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